Sulphate Scale Problems in Producing Wells West Welch (San Andres) Unit - a Case History

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INTRODUCTION

After five years of waterflooding, the West Welch (San Andres) Unit was experiencing acute production declines caused by calcium sulphate scale forming in the producing wells. A program was initiated at that time to investigate the cause of the scale growth and means of correcting it.

The purpose of this paper is to summarize the field and laboratory work done to inhibit and remove $CaSO_4$ scale from the producing wells in this waterflood. Evaluation of scale inhibitors and methods of applying them are covered as well as scale removal chemicals and procedures. In gathering and interpreting data a new use of an old tool, the caliper survey, was initiated with good success. Most of this work has been done in the last 1-1/2 years and it is not yet considered finished as other questions must be answered for a long term and lasting conclusion.

The last few years have seen many large San Andres waterfloods initiated in this area and more are to come in the future. The San Andres formation contains large amounts of anhydrite (anhydrous $CaSO_4$). The $CaSO_4$ can be picked up by the advancing flood water and re-deposited at the producing well as gypsum ($CaSO_4 \cdot 2H_2O$). Although the data presented in this paper is taken from only one San Andres flood, it is the hope of the author that it will be of some assistance to other operators of San Andres floods and therefore be of general interest.

GENERAL INFORMATION

The Welch Field is located in the northwest corner of Dawson County, Texas. Production is from the San Andres formation at an average depth of 4950 ft. Completion practice has been to set 5-1/2 in. casing on top of the porosity with 4-3/4 in. open hole through the pay zone. There is approximately 100 ft of open hole with 65 ft of effective pay. Most of the field was developed in the 1940's with some areas overlapping into the 50's. Cities Service Oil Co. initiated a pilot waterflood on what is now Tract #48 (Fig. 1) during 1955. A paper by Mr. G. E. Hendrickson was published in the August 1961 edition of the **Journal of Petroleum Technology** describing this pilot flood. The pilot flood was a success and the West Welch (San Andres) Unit was formed in 1960. Expansion of the flood followed that year on an 80-acre, 5-spot pattern. This pattern was changed to the present 40-acre, 5-spot due to a directional fracture pattern present in the formation.

The injected water is a mixture of Santa Rosa supply water and San Andres produced water in a 9:1 ratio. All of the mixed waters are filtered but not treated, and the injection system is of the closed type. In Table 1 are average values of the important constituents of the two waters.

TABLE I

Constituents	San Andres	Santa Rosa
Chloride (Cl)	38,000 mg/l	3,260 mg/l
Sulphate (SO_4)	3,870 mg/l	3,300 mg/l
Magnesium (Mg)	760 mg/l	70 mg/l
Calcium (Ca)	2,670 mg/l	100 mg/l

SCALING AND TREATMENT HISTORY

Many areas within the West Welch Unit experienced some scaling problems during primary production. Possibly there was more scaling during this period than was recognized at the time. Usually scale growth in a well was not identified as such unless the tubing became stuck. Other production declines were considered normal for primary production.

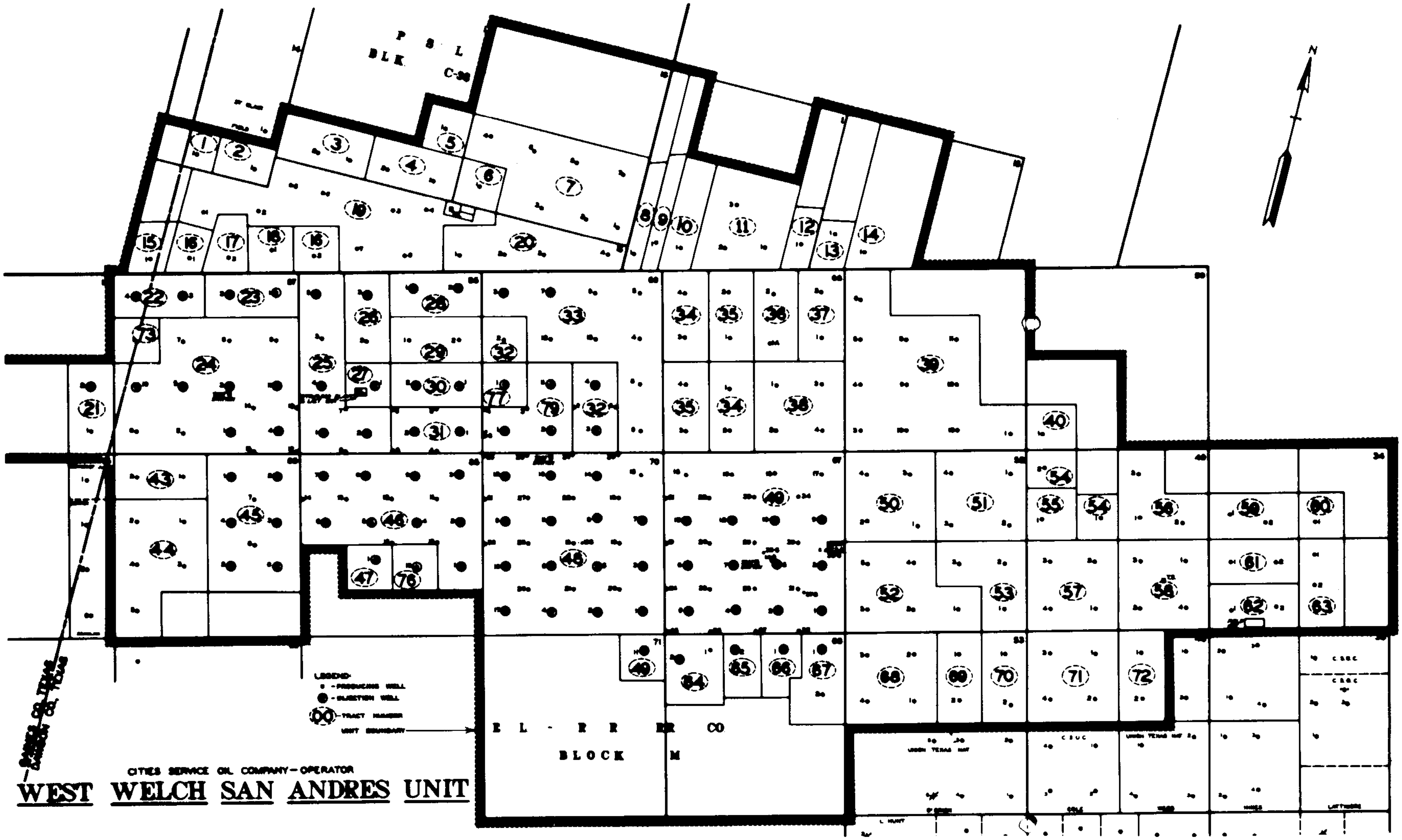

CITIES SERVICE OIL COMPANY—OPERATOR
WEST WELCH SAN ANDRES UNIT
BLOCK

FIG. 1

Several chemicals were used for inhibition of scale during this period, some as early as 1949. In general they were of the inorganic phosphate type, as well as other sequestering and chelating chemicals. In some cases these treatments appeared to be successful but invariably, failures would occur, causing the treatments to be discontinued. At the time of the pattern change which required in-fill drilling, the well completion practice was to pack the wellbore with controlled solubility phosphates (CSP). This practice followed until 1963 when it became the practice to frac the formation with CSP crystals. This policy was in effect at the time of the recent work.

Scale removal treatments through this period were of the convertor type followed by acid. Several chemicals were used such as NaOH, $NaHCO_3$, KOH, NH_4HCO_3, etc. The results of these first treatments were erratic. Chemical analysis after treatment indicated $CaSO_4$ was dissolved, but production increases did not always follow. Gradually it became the practice to drill out to total depth prior to chemical treatment. Production increases and the success-failure ratio improved after this policy was initiated. Generally the chemicals were dumped down the annulus during these earlier stages. Later it became necessary to displace them to bottom due to the increased bottomhole pressures resulting from the waterflood.

The most recent work (and the main subject of this paper) on scale inhibition and removal was precipitated by the sharp production declines being experienced in the West Welch Unit during the early part of 1965.

SCALE PROGRAM INITIATED

At the initiation of an intensive scale program in 1965 a few facts were known. (1) Laboratory tests indicated that at surface conditions and with respect to their tendencies to form $CaSO_4$ scale, the Santa Rosa and San Andres waters were compatible. No scale had been found in the injection system or injection wells to further substantiate this fact. (2) $CaSO_4$ scale was the particular scale forming in the producing well's borehole and causing the production decreases. (3) No scale was forming on the tubing, rods or pump; it was all confined to the open hole.

Many facts were not known and several questions needed answers. (1) Could better scale removal chemicals and/or procedures be employed to give bigger production increases with longer life? (2) Where was the scale growing and at what rate? (3) Did the scale grow just in the wellbore or did it extend into the formation porosity? (4) What chemicals and procedures would inhibit the scale growth? (5) What caused the scale to grow in the first place?

WATER ANALYSIS

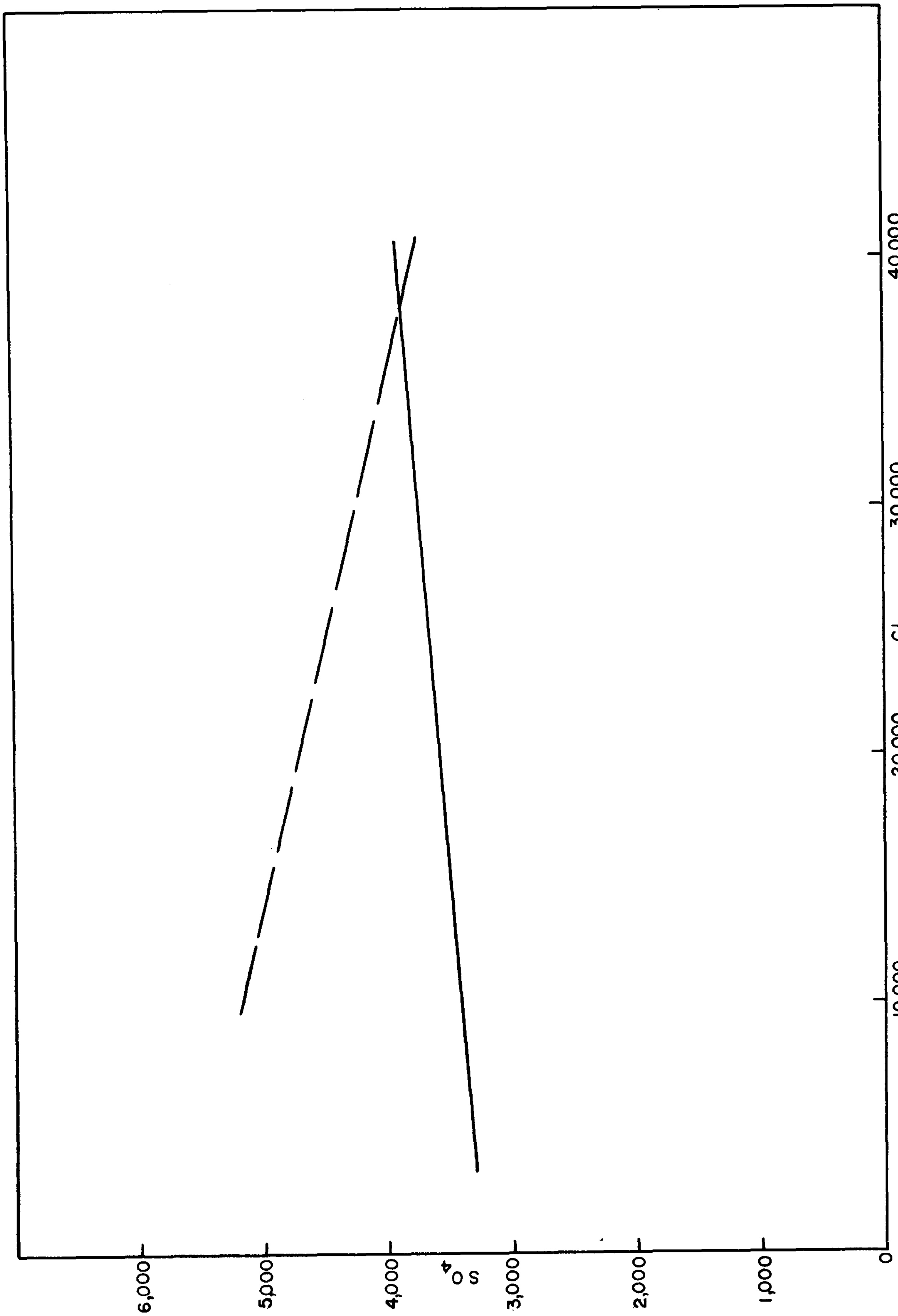
Since the constituents of any scale are associated with the water phase of production, water analysis was a logical area in which to start our investigation.

The purpose of these analyses was to determine if there was any relationship between the amount of dilution with Santa Rosa water and the scale problem as indicated by the chloride content.

Knowing that the San Andres formation contains large amounts of anhydrite ($CaSO_4$) and the injected water (Santa Rosa) would pass over the maximum amount of formation (and anhydrite), from injector to producer, it followed that as the percentage of injected water increased at the producing well, an increase in SO_4 and Ca would be seen in the produced water analysis, if the assumption that the advancing flood water does dissolve anhydrite as it passes through the formation was correct.

Figures 2 and 3 present the data gathered from water analyses. Figure 2 is a plot of SO_4 against Cl content. The solid line represents a straight dilution of San Andres water with Santa Rosa water and the corresponding SO_4 content expected in the produced water. The dashed line represents the actual SO_4 content of the produced water in wells producing from 80 per cent Santa Rosa water to 0 per cent Santa Rosa. It is evident that as the Santa Rosa water percentage increases, the SO_4 content of the produced water increases, indicating that anhydrite within the formation is being dissolved. Although Fig. 3 indicates basically the same conclusion as Fig. 2, it is not as clear or definite about it. There is an increase in Ca content above the expected from straight dilution of the two waters indicating that anhydrite is dissolved from the formation.

A word of caution about drawing too many conclusions from Figs. 2 and 3—even though increases in Ca and SO_4 were found as the percentage of injected water increased in the pro-



6,000
5,000
4,000
3,000
2,000
1,000
0
SO_4
10,000
20,000
30,000
40,000
CL

FIG. 2

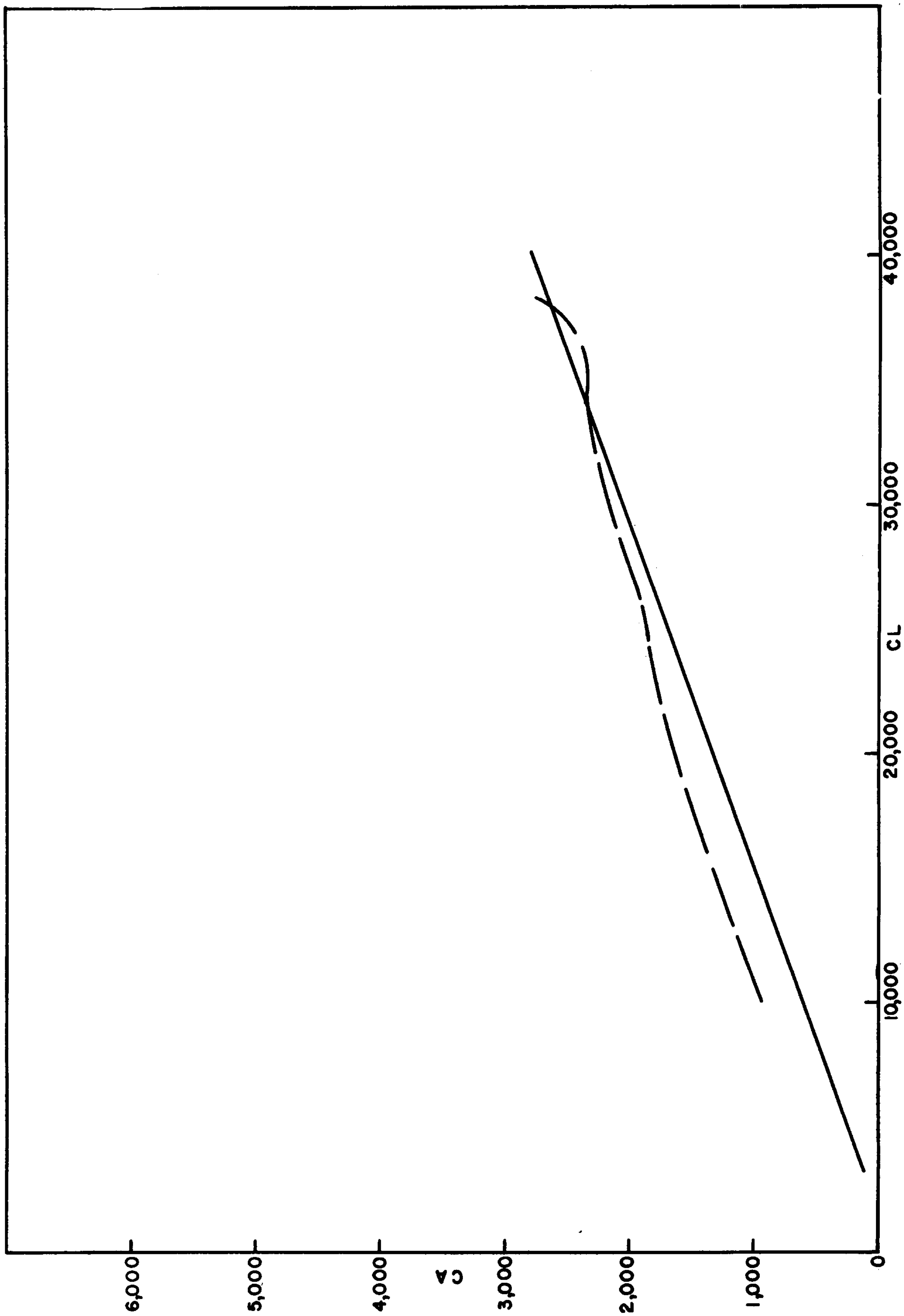


FIG. 3

ducing well, this does not allow us to say an increase in scale growth will follow or even that it will be formed at all. It does allow the conclusion that anhydrite ($CaSO_4$) is dissolved by the advancing flood water.

Although a detailed discussion on the solubility of salts is beyond the scope of this paper, a few comments on this subject seem appropriate The solubility of salts is determined by temperature, pressure and other salt content of the water. In this particular case the salt content of sodium, magnesium and excess Ca over SO_4 or excess of SO_4 over Ca are the controlling constituents. Generally an increase in temperature, pressure or other salt content increases the solubility of the water for Ca and SO_4 Conversely, a decrease in any of these will decrease the solubility of the water to Ca and SO_4. As the flood water advances through the formation an equilibrium is set up between all of these factors, possibly to a point of saturation. If at the producing well any one of these factors is changed, the equilibrium is upset and scale growth may occur.

As more knowledge was gained as to the actual scale growth rate and severity in a particular well, the water analysis data agreed very well with the well's scale rate. As the produced water of a well approached 30 per cent Santa Rosa, scale growth became apparent. The scale growth became very severe as the percentage of Santa Rosa approached 50 per cent and above. Water analysis also indicated that the quantity of water produced had no apparent effect on the scale growth rate; it was the quality of water that controlled.

It is difficult to say that the injection water by itself is causing the scale, because of the other factors that affect scale growth. The wells experiencing severe scale growth are in the older part of the flood. Of course, the percentage of injection water in the producing well is highest in this area, but this is also the area of highest reservoir pressure, which is a factor in forming scale. Also, the same wells will experience the largest temperature drop at the wellbore because of the higher $\triangle P$ across the formation face, another factor in scale growth. These factors cannot be altered significantly without materially changing the flood's oil production.

Again, the main point the water analysis shows is that the flood water does pick up and carry to the producing well the constituents for $CaSO_4$ scale. If other factors are right at this point, scale will be formed.

CALIPER SURVEYS

The caliper survey was a major tool in this investigation. Through its use, the exact point and rate of scale growth in the open hole was determined for individual wells. It was possible to evaluate chemicals and procedures in a relatively short time, two to three weeks, with the caliper survey. Other methods of obtaining the same information would have taken a great deal more time and money, plus possibly not being as exact.

The first calipers were run to determine the areas of scale growth and its rate. These calipers indicated no massive scale growth over the formation face, but rather over thin intervals of the producing zone. These zones continued to grow until the open hole was bridged, and production from below the bridge was shut off. The fact that scale growth was bridging the hole in small intervals shed light on work that had been done in the past as well as work to come. It made it possible to correlate seemingly unrelated facts into concrete conclusions.

As might be expected, the first zones to experience scale growth were the most permeable ones. Figure 4 is a correlation of the caliper log, neutron log and permeability from core analysis, on well 48-22. The caliper log shows the maximum scale growth to be occurring at 4886 ft. From the core analysis, the maximum permeability also is at 4886 ft and the neutron indicates good porosity at this point. As the flood water advances and breaks through in the next more permeable zone, we would expect to see scale growth there, as has already occurred at 4894 ft in this particular well. Through the use of calipers, scale growth rates for particular wells were determined. Some wells had such severe growth that the open hole would be bridged in two weeks. It was never dreamed that growth rates of this magnitude were being experienced prior to the use of calipers.

SCALE REMOVAL TREATMENTS

Both water analysis and calipers were used to evaluate scale removal treatments. As stated previously, the practice on scale treatments at the time of the recent work was (1) drill out to total depth; (2) treat open hole with scale-con-

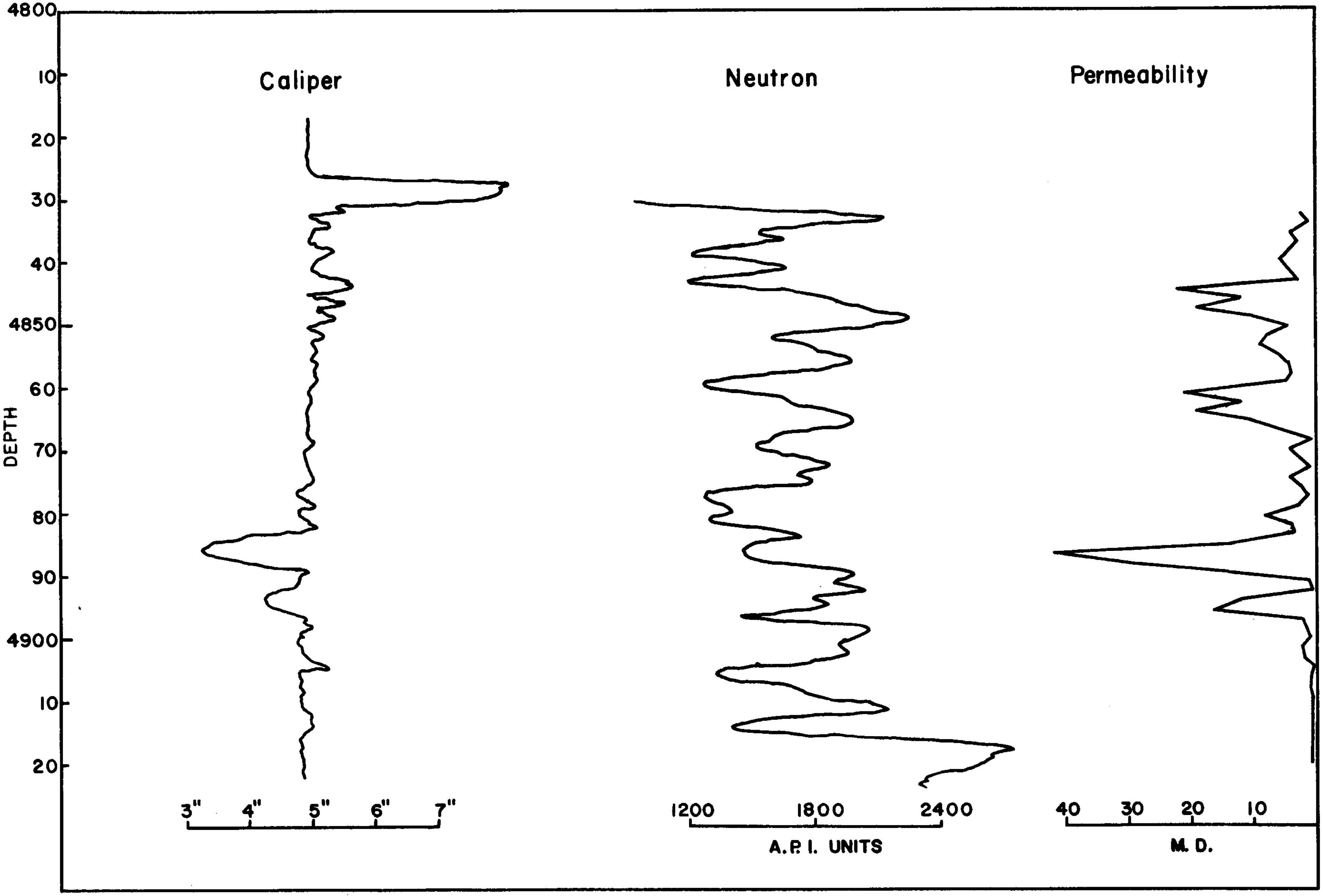


Fig. 4 Well 48-22

verting chemicals; (3) acidize converted scale. Although good production increases were experienced after a scale treatment, it was hoped that by investigating the total procedure, each step could be evaluated and possibly, improvements made, resulting in less downtime and larger production increases with longer life.

Two groups of wells were selected for this investigation. One group was drilled out and treated as described above with water samples and production tests taken after drill out, chemical treatment and acidizing. The results from these wells indicated that (1) most of the production increase came from the drill out with the remainder coming from the acidizing; (2) water analysis indicated some scale was removed, since the SO_4 count increased after chemical treatment and acidizing; (3) dolomite was dissolved by the acid with similar increases in Ca and Mg after acidizing. The second group of wells was drilled out, then produced to allow some scale growth in the wellbore. After scale growth was established by caliper the wells were treated with chemical and acid. Production tests and water samples were taken as on the first group of wells. Caliper surveys were run prior to chemical treatment and after acidizing. The production tests and water analysis results were similar to the first group of wells. The caliper surveys indicated little or no scale was removed by the chemicals and acid. This last result was somewhat surprising.

Laboratory work being conducted at this time experienced a similar phenomenon. While duplicating a field chemical and acidizing treatment on a sample of scale the following was found: the material remaining after performing these treatments "was still a single consolidated piece with little change in volume, in spite of having lost half its weight". This unusual aspect of this investigation has not yet been explained.

From the calipers run during this and other treatments on several wells one point became increasingly evident: over-acidizing during these treatments could become detrimental to future remedial and production practices. Figure 5 illustrates the effect of over-acidizing on the open hole as indicated by caliper. Starting at the left of Fig. 5 the open hole was approximately 4-3/4 in before any treatments. The middle caliper in Fig. 5 was taken after two treatments and the top portion of the open hole has increased to approximately 5 in. The last caliper in Fig. 5 was taken after two additional treatments and the open holes has increased to 5-1/2 in. on the top portion with the bottom increasing to over 5 in.

It is easy to see the increased difficulty of mechanically or chemically removing the scale from the wellbore as its diameter is increased. Under-reaming would be required as the diameter became larger than 5 in., as well as larger chemical treatments requiring more money and time to remove the scale.

Due to these findings, it became necessary in the West Welch Unit to discontinue chemical treatments as a means of removing scale from the wellbore. Since scale was growing at small intervals in the open hole and most of the production increase came after a drill out, it was decided to permanently install drilling bits on the tubing of severely scaling wells. These wells were to be drilled out at periodic intervals, depending on their scale growth rate, with power tongs and no circulation. This economical practice was instrumental in leveling and maintaining production in the Unit at the highest possible point.

Some conclusions are possible from this work on scale removal treatments that apply to this type treatment in general. Drilling out prior to treatment is most important. This enables the chemical to contact the total pay zone. This single practice increased the success of scale treatments in the Welch Field prior to the latest investigations. It is also probably why larger SO_4 counts were not recorded after treatments in the more recent work. Large amounts of scale were removed by drill out, therefore only small amounts were left for reaction with the chemicals. Proper placement of the chemicals at the points of scale growth is an important factor in increasing the success of scale treatments. This is best achieved by displacing the chemicals down the tubing or annulus with oil.

SCALE INHIBITION

One of the first steps in this investigation was to evaluate the scale inhibition of CSP, which was presently being employed in the producing well either in a packing or fracing job. Calipers on wells that were packed or fraced indicated scale growth in the wellbore. All of these

CALIPERS

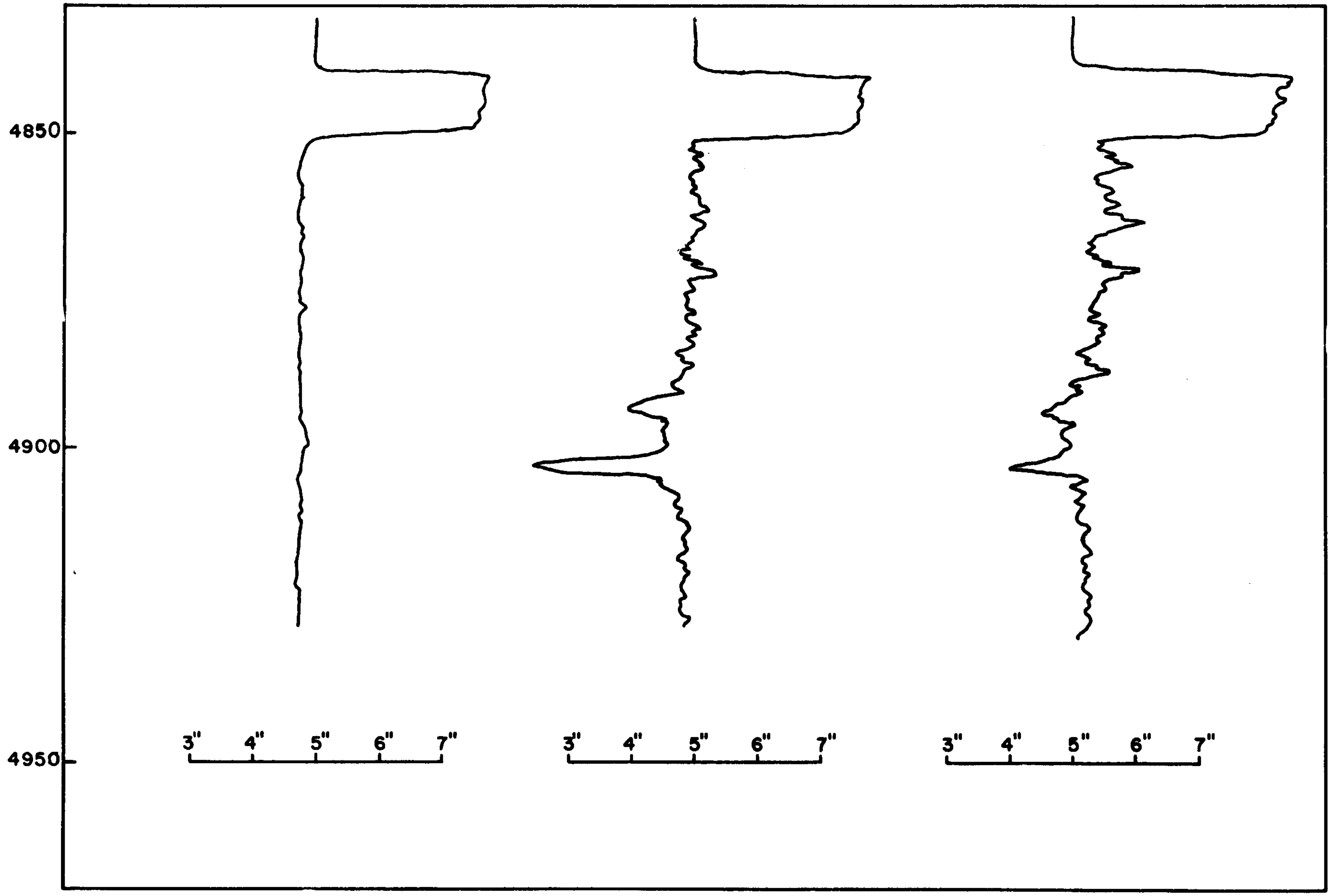


FIG. 5

wells had high phosphate counts, well above the minimum for scale inhibition. The failure of CSP to inhibit scale in these type treatments is surely not the fault of the chemical, but in the application. It is widely known that CSP will inhibit scale growth in certain applications. Since the scale was growing on the formation face, the pack jobs probably failed because the phosphate did not mix with the produced water in the wellbore until after the scale had actually formed. In the case of the frac jobs the phosphate was not in the proper zones within the formation. Therefore no water passed over it or it reverted too quickly. However, CSP was discontinued at this time as an inhibitor in this waterflood.

Realizing that it is very difficult to change the factors that cause scale growth without adversely affecting oil production, it was still felt that some type scale inhibition, other than CSP, was the proper angle to attack the scale problem in the West Welch Unit. Liquid scale inhibitors, for many reasons, seemed superior to any solids and they were chosen to be the subject of this phase of the investigation. Although liquid inhibitors were used in the past without success, it was hoped that under more controlled conditions and new applications their chances of success would be improved.

Basically, two methods of applying the liquid scale inhibitors were investigated. One method was to continuously feed the chemical down the annulus with the tubing set near bottom so the chemical would pass the formation face before being produced out of the well through the tubing. The second method was a "squeeze" with the chemical mixed in oil or water and displaced into the formation followed by an overflush. Most of the chemicals tested were evaluated in laboratory tests to insure their ability to inhibit scale growth. These tests were relative tests and not necessarily precisely what was expected to take place in actual field tests.

As stated in the first method, the tubing was set near bottom. A chemical pump at the surface injected chemical down the annulus of the treated well. There was a continuous flush of produced fluid fed into the annulus from the lead line. The chemical pump and flush lines were checked several times a day to insure they were operating properly. Three water samples were taken daily for analysis. These samples indicated the chemical content in the produced fluid was always higher than minimum recommendations for scale inhibition. In several wells tested in this manner scale growth was indicated within three weeks. In most cases the tubing was stuck in this same period of time. Several different chemicals were tested with the same ultimate results, continued scale growth. Therefore, this method of treatment was labeled a failure. Here again, the failure was probably due to misapplication and not the chemicals. From these tests it became evident the chemicals must be mixed with the formation waters prior to the area of scale growth at the formation face.

The second method under study for applying inhibitors seemed to have some advantage over the first method used. In this "squeeze" type method the chemical would be produced back with the formation waters and be available for inhibition at the formation face where the scale was forming. This method would not require daily inspection of a chemical pump or flush line, plus other surface handling problems. The tubing could be left in the casing to prevent possible sticking in the open hole.

Several chemicals were tested with this "squeeze" method. Some chemicals were mixed in water, others in oil and displaced with oil or water. The chemical mixture was displaced down the tubing at between 1/2 BPM and 1 BPM on the first wells treated. The results from the first wells treated in this manner were very erratic. Some wells indicated no change in scale growth. One chemical showed some retardation in growth on two wells. Further tests on other wells were failures with the same chemical. An injection profile run on one of these wells as it was being treated was inconclusive because of rate changes during treatment.

From these results it appeared the chemicals were either (1) not entering the scale zones or (2) were produced back too quickly, since previous laboratory tests indicated the chemicals all had some scale inhibition qualities. At the time this work was conducted accurate tests for the quantity of chemical returning were not available. This was particularly true of the organic phosphates. In the case of some chemicals there was absolutely no method of testing the produced water for chemical concentration.

The next series of tests was conducted with

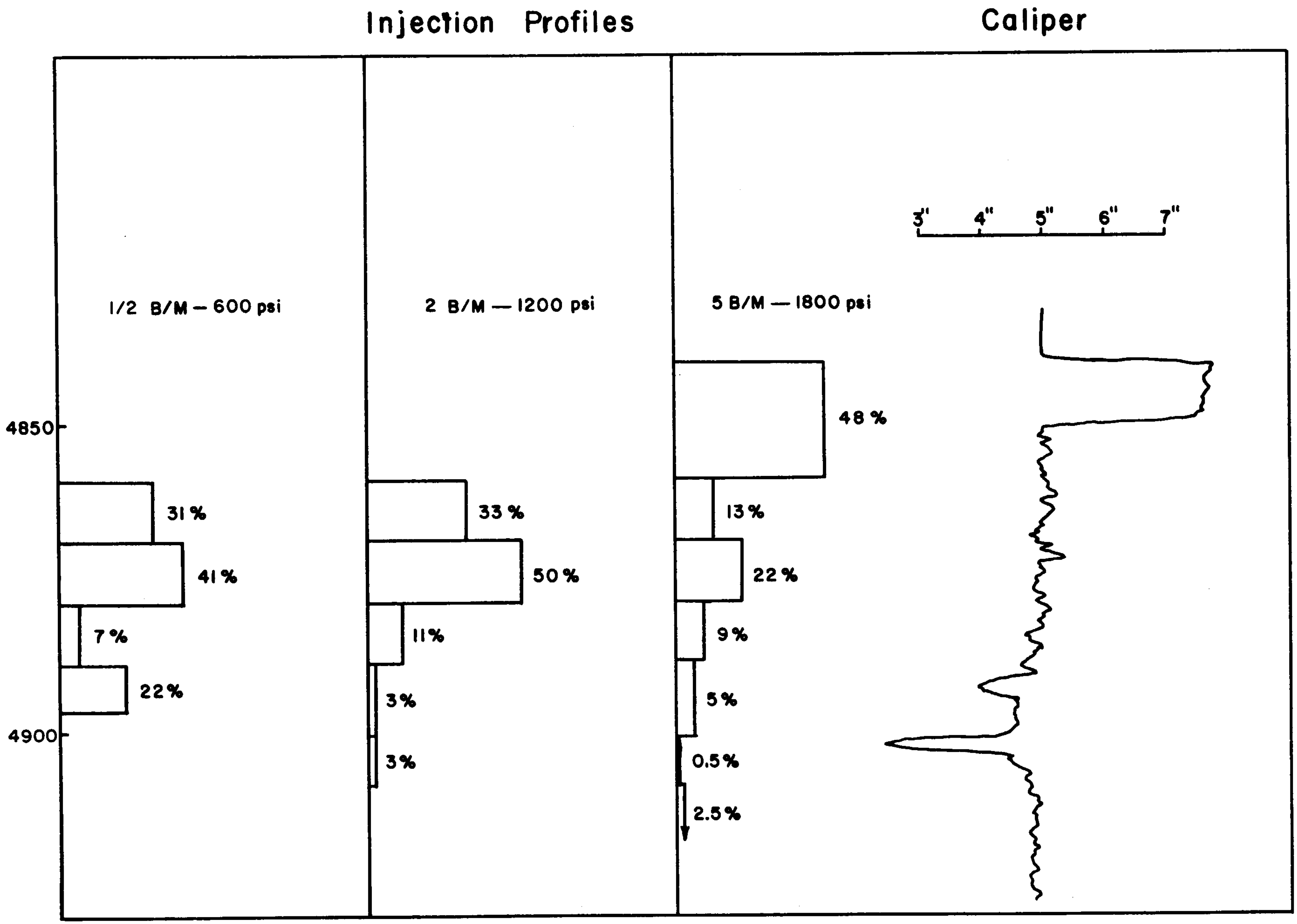


Fig. 6 Well 49-19

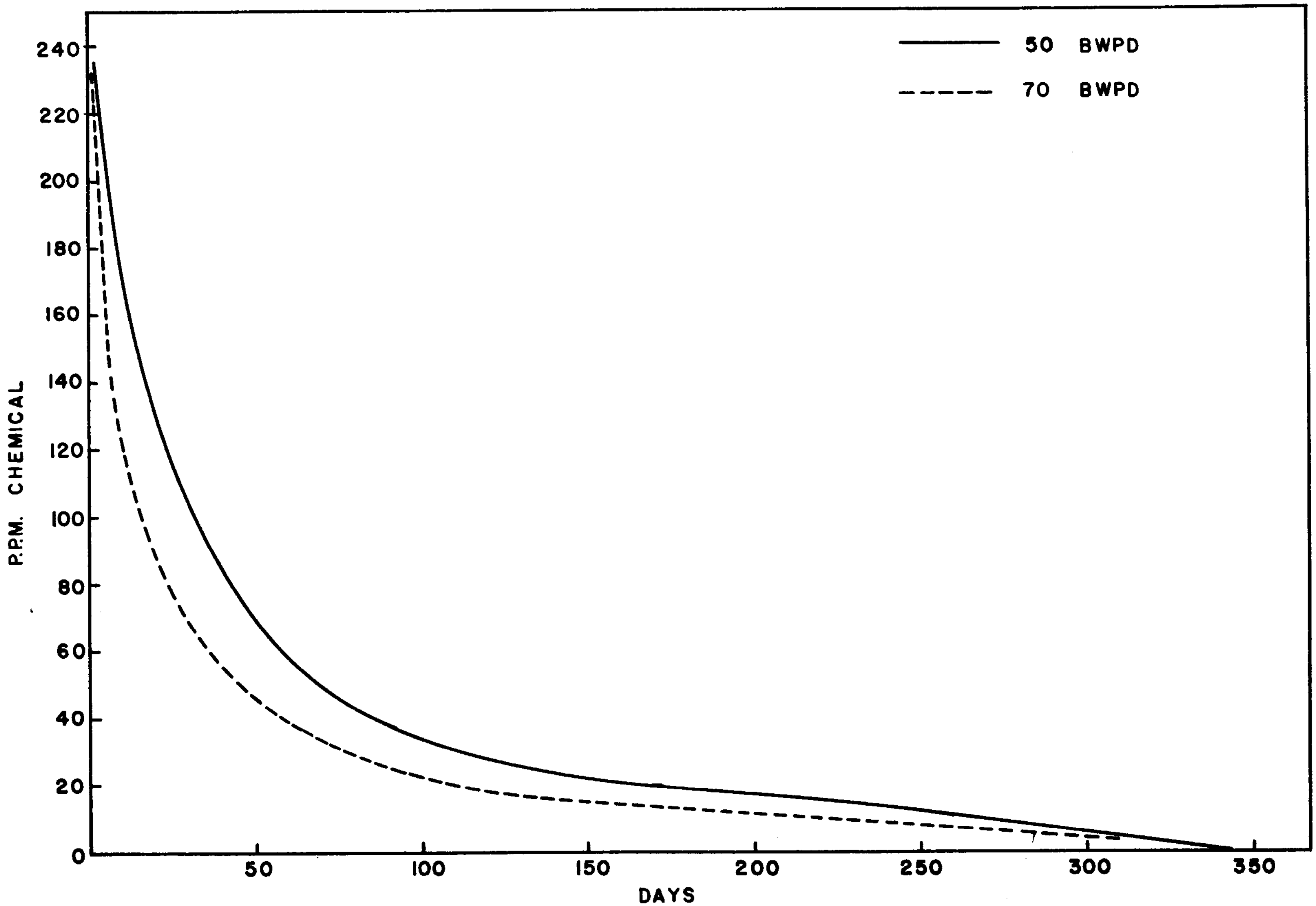

50 BWPD
70 BWPD
P.P.M. CHEMICAL
240
220
200
180
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350
DAYS

FIG. 7

open hole packers in an effort to isolate the scale zone from the rest of the pay. Single and straddle open-hole packers were tested. In all cases communication was experienced after a few barrels were displaced into the formation. These tests indicated the communication was through fractures in the formation and not just at the packer element. As much as 70 bbl were displaced in one well before it communicated. All wells treated with open-hole packers still experienced scale growth after treatment.

After failure to isolate the scale zone by open-hole packers, additional injection profiles seemed the only means of getting the necessary information for proper placement of the treating chemicals. Figure 6 is a summary of the profile data gathered on one well. The three profiles shown indicate very small amounts of fluid entering the scale zones as indicated by caliper survey at the far right. After this particular well, 49-19, was treated with chemical, the top scale zone at 4893 ft stopped growing. Since it was treated at approximately 1/2 BPM, the zone at 4893 ft probably took 22 per cent of the chemical, which is indicated by the profile at the left. This data tied in so well with past treating experience that it was obvious a different method of placing the chemical in the scale zones was necessary.

It was decided that fracing the formation at a high rate might open all zones, including scale zones, so they would take some chemical during treatment. Two wells, with known scale growth rates, were sandfraced with the scale inhibitor used as a spearhead for the frac. The wells were shut in for 48 hours to allow the chemical to absorb to the formation. These wells normally experienced scale growth in three weeks, with one bridging the open hole in less time than this on occasions. After this treatment no scale was indicated by caliper in the open hole on either well to the time of this writing—six months after treatment.

Figure 7 is a curve of the indicated chemical content of the produced water after treatment of the two treated wells. There is some difference in the two curves which is probably due to the difference in water production of the wells. The well producing 70 BWPD has a sharper initial decline but levels out similar to the well producing 50 BWPD. This curve indicates the chemical used has good adsorption qualities and it is feeding back in sufficient quantities to inhibit scale growth. Of course, these qualities are essential in this type treatment.

Only time will tell how long this treatment will last or what concentrations of chemical are necessary for scale inhibition. It now appears that at least nine months' scale inhibition can be expected for this type treatment and chemical. This time could be extended with a chemical having better adsorption, de-adsorption qualities and lower concentrations required for scale inhibition.

Summarizing the work on "Squeezing" scale inhibitors the following points appear significant:

(1) A chemical that actually inhibits scale growth must be found. This can be done by a simple screening test or intensive laboratory work, possibly from previous experience.

(2) The chemical must have good adsorption, de-adsorption qualities to adhere to the formation and feed back over an extended period.

(3) The chemical must not lose its effectiveness with time.

(4) A procedure for placing the chemical in the zones experiencing scale growth must be found.

These conditions were met in this investigation for the particular area under study, the West Welch Unit. The chemical was tested at surface conditions and it did inhibit scale growth. The chemical was especially designed with good adsorption, de-adsorption qualities by its producer. The chemical was an organic phosphate, therefore it would not revert with time. The chemical was displaced into the formation at 10 BPM, well above fracture rate. Some chemical apparently was placed in the scaling zone, since there is no scale growth six months after treatment.

FUTURE WORK

Part of the work on water analysis included the calculation and construction of solubility curves for Santa Rosa and San Andres waters. The solubility curves were adjusted to saturated conditions at bottomhole temperature. No data was available to adjust these curves for bottomhole pressure. The curves derived indicated scale growth should occur at water dilution percentages very close to actual field experience. Additional solubility curves using fresh water and San Andres water were constructed. These curves were also adjusted for saturated conditions at bottomhole temperature but not pressure. These solubility curves definitely indicated the use of fresh water would reduce the scale-forming possibilities. It must be remembered that these curves were not adjusted for pressure and we are on somewhat treacherous ground while working with solubility curves in the first place.

Due to additional development and need for more supply water, plus the above analytical data, the supply water for this waterflood will be changed to fresh water in 1967. This is not to indicate that we think the fresh water will eliminate the scale problem in the West Welch Unit, but it is believed it will reduce this problem. If fresh water will reduce the scale problem, the economics are most attractive at this time to make that change. Of course, no benefit will be realized from the fresh water injection until it reaches the producing well. This could be several years since over 23,000,000 bbl of Santa Rosa water have been injected in the older parts of the flood. Benefits may come sooner in the newly developed areas as no other type injection has occurred there.

In the intervening time, work to improve the present squeeze chemical and procedure will continue. Procedures for placing more of the chemical in the scaling zones will be explored. The search for new chemicals with better absorption, de-adsorption qualities and lower concentration requirements for scale inhibition will continue. If the fresh water does not eliminate or greatly reduce the scale problem, new methods to inhibit scale growth must be employed for the West Welch Unit to be an economic success.